



# Phased Array Ultrasonic Evaluation of Space Shuttle Main Engine (SSME) Nozzle Weld

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## Review of Progress in Quantitative NDE Ultrasonic Transducer Arrays Bowdoin College, Brunswick, Maine July 2001

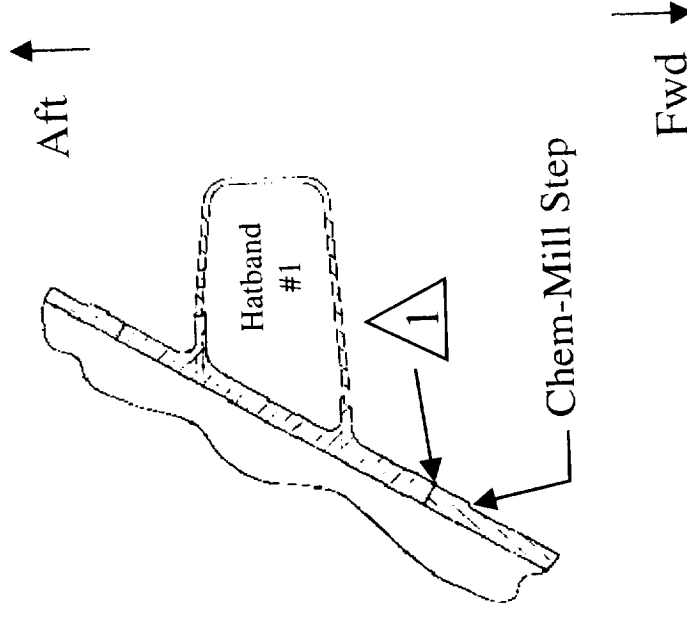
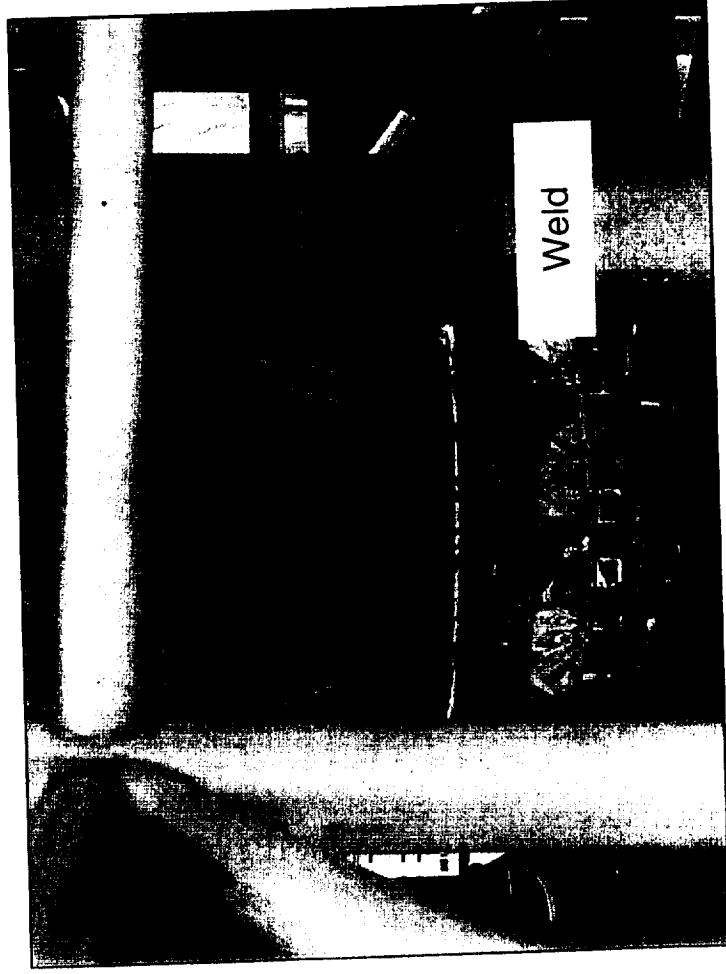
S. James, Boeing Space and Communications, Canoga Park, CA  
J. Engel, Boeing Space and Communications, Huntington Beach, CA  
D. Kimbrough, Boeing Space and Communications, Canoga Park, CA  
M. Suits, NASA – Marshall Space Flight Center, Huntsville, AL





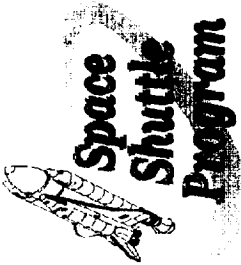
# Phased Array Ultrasonic Examination of SSME Nozzle Weld

- Issue
  - Potential linear indications (.300" - 1.900") in a nozzle jacket weld



**Nozzle in Stacked Tube  
Braze Assembly Fixture**





# Phased Array Ultrasonic Examination of SSME Nozzle Weld

## • Solutions Considered

- Leave Jacket assembly "As Is" without performing any additional work / inspections
  - Unable to quantify the defect depth from x-ray
  - Unable to determine if CEI requirements would be met.
- De-Stack Nozzle
- Re-perform X-ray on discrepant regions
  - Removal of vacuum bag, coolant tubes, and braze alloy and also requires removal of EDNI repair to perform radiographic inspection to the original requirements.
    - *Work in excess of 1000hrs*
- Contamination concerns if a partial tube de-stack operation were to be performed
- Find an alternate inspection technique to validate weld joint





# Phased Array Ultrasonic Examination of SSME Nozzle Weld

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- **Challenge:** Hardware can not be moved, rigid tooling, one side accessibility
  - Stacked Braze Assembly
    - Inverted Nozzle with EDNi, braze alloy, coolant tubes, and vacuum bag in place, ready for braze cycle.
    - Part cannot be re-x-rayed to the original requirements in current configuration.
    - Visual examination of inside diameter of weld cannot be accomplished





# Phased Array Ultrasonic Examination of SSME Nozzle Weld

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- NDT Evaluation Approach

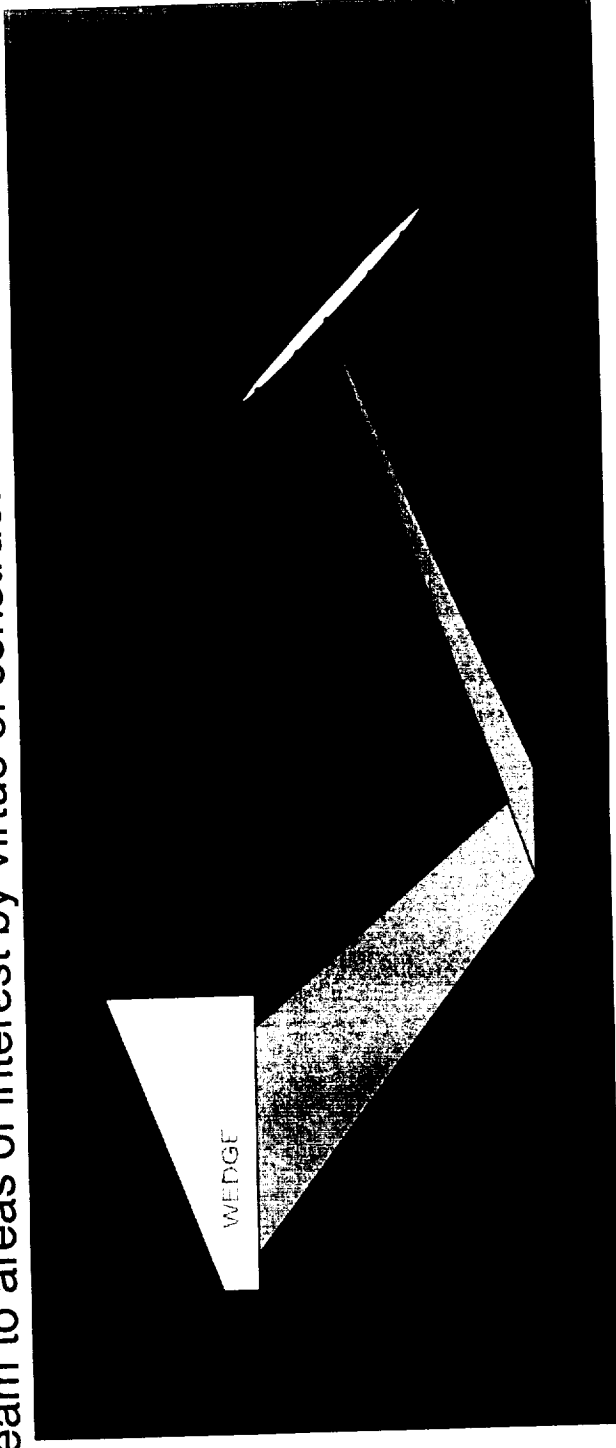
- The Boeing NDT Process Action Team was consulted & consensus method was ultrasonics
- Initial Steps
  - Principle Level III UT at Renton provided ultrasonic modeling of weld joint and 60 degree shear wave probe
  - Level III UT at Huntington Beach offered Phased Array UT
  - NDT scientist at Rockwell Science Center conducted Ultrasonic Modeling based on added nickel plating.
- Method Selection - Phased Array UT & Conventional “A scan” Shear Wave
  - Phased Array was selected based on the greatest detection sensitivity and comprehensive selection of angle interrogations.





# Phased Array Ultrasonic Examination of SSME Nozzle Weld

- **What is Phased Array Ultrasonics?**
  - Phased Array Ultrasonics is an electronically controlled method which uses multi-element piezo-electric crystals to form and shape an ultrasonic beam. "Focal Laws" are created by software controls that are used to define electronic delays across the probe elements to steer and focus the beam to areas of interest by virtue of constructive beam interference.





# Phased Array Ultrasonic Examination of SSME Nozzle Weld

## Conventional Shear-Wave & Phased Array Techniques

Comparison of UT Technique Capabilities		
Items Compared	Conventional UT	Phased Array UT
Real Time	Real Time on Cathode Ray Tube	Computer Recorded Data Manipulation capabilities
Scanning	"A" scan only	"A", "B", & "C" scan
Scanning Angles	Single angle based on "shoe"	Multiple angles based on optimization
Scanning Views	1 Beam per probe	48 x 4=192 Beams (50,55,60,65)
Scanning Method	Manual	Automated
Scanning Medium	Gel or DI Water	DI Water
Scanning Hardware	No Tooling Required	Tooling Required





# Phased Array Ultrasonic Examination of SSME Nozzle Weld

## Risk X-ray vs. Phased Array Risk Analysis

Phased Array more sensitive than X-ray	Other indications that were previously unknown may result.
Interpretation of data Immature	Phased Array provides multiple methods of data quantification. Includes A, B, and C scans. Phased Array uses reference standard vs. X-ray image quality indicator (penetrameter)
Single Expert	Data capture, review, and final assessment scrutinized under 6 UT experts as opposed to the normal level II, level III X-ray evaluation. Final analysis was concurred by all experts.
Phased Array Detectability of Off-Angle Defects Limited	Used swiveling technique with conventional A-scan to evaluate Off angle indications
Duplication of Setup on Part	Modified Phased Array Shoe, Attached standard to part to confirm process Backed up all scans with multiple phased array scans and conventional "A" scans



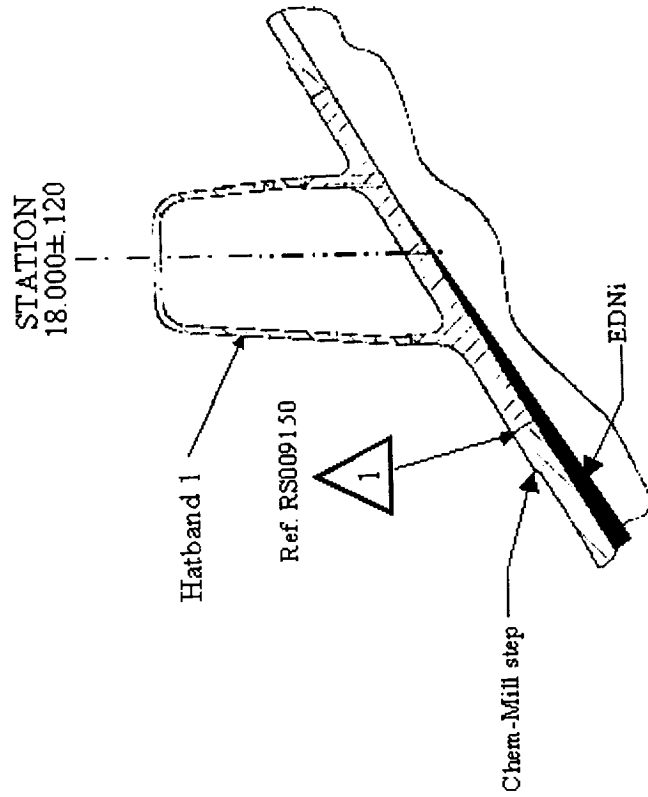




# Phased Array Ultrasonic Examination of SSME Nozzle Weld

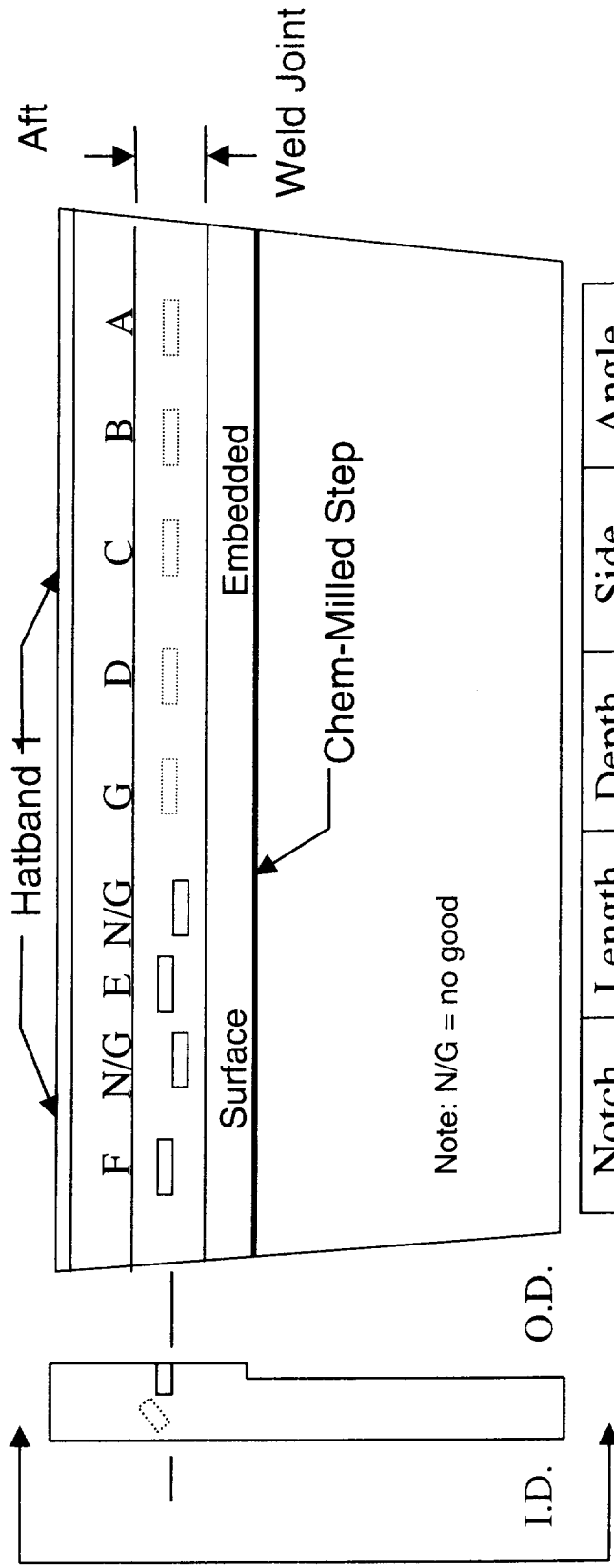
## Reference Standard Fabrication

- Need to be as close as possible to replicate hardware configuration
  - Similar section of Weld from scrapped nozzle
  - Removed brazed tubes
- Artificial Flaws
  - EDM 30° notch orientation determined by weld prep
  - Notch placement established with information based on x-ray results
  - Notch dimensions determined (Length & Depth) by Stress & NDT Engineers
  - Measured by metrology for verification
- Nickel plating on standard to simulate hardware
  - Chem-Mill edge blended to .050" from edge of Weld joint 1 on both hardware & standard to optimize UT response.





# Phased Array Ultrasonic Examination of SSME Nozzle Weld



Notch	Length	Depth	Side	Angle
A	.300	.012	I.D.	30°
B	.300	.018	I.D.	30°
C	.300	.024	I.D.	30°
D	.300	.036	I.D.	30°
E	.300	.012	O.D.	Normal
F	.300	.036	O.D.	Normal
G	.300	.030	I.D.	30°

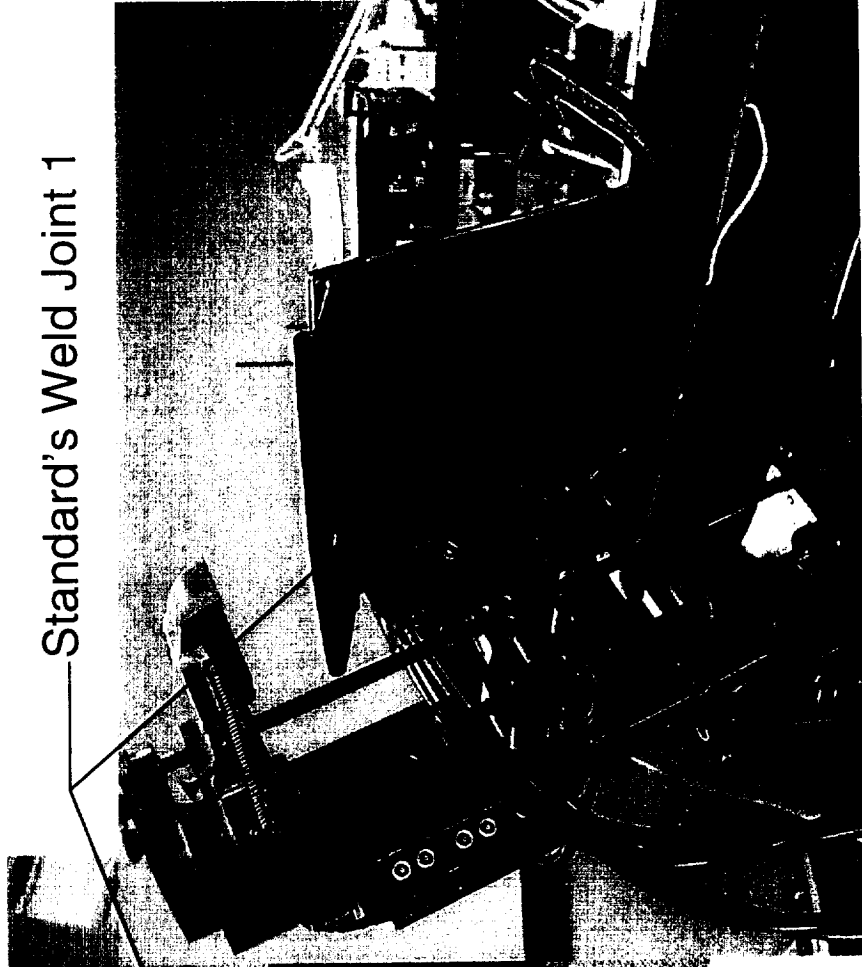




# Phased Array Ultrasonic Examination of SSME Nozzle Weld



Conventional Shear Wave Set-up



Standard's Weld Joint 1



Phased Array UT Set-up





# Phased Array Ultrasonic Examination of SSME Nozzle Weld

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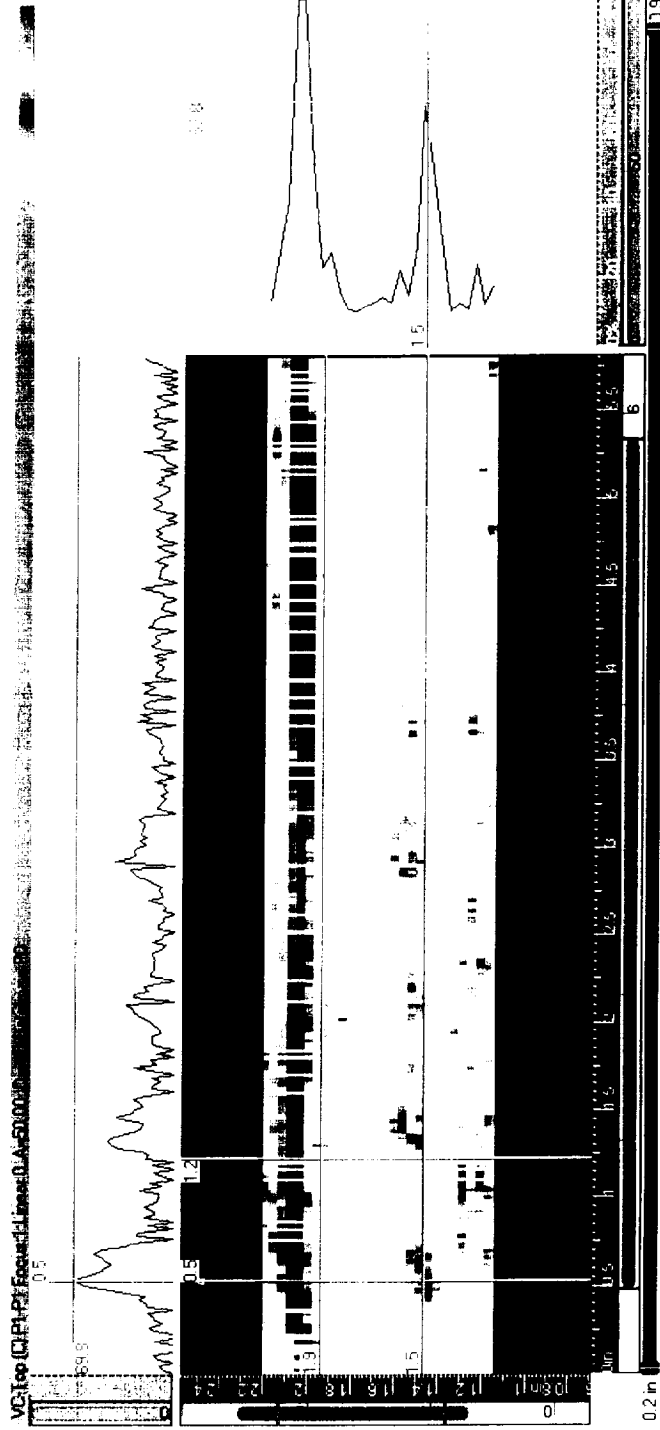
- Field set-up was duplicated to the greatest extent possible in the laboratory.
- Phased Array ultrasonic technique developed and validated prior to weld evaluation.
  - Results of investigation: Phased Array UT technique/ conventional A scan are capable of detecting notches as small as 10% of wall thickness (.012" deep X .300" long).





# Phased Array Ultrasonic Examination of SSME Nozzle Weld

- Phased Array C-scan image
- Angle 50 degrees



.012" deep EDM notch @ a 3:1 S/N ratio





# Phased Array Ultrasonic Examination of SSME Nozzle Weld



Phased Array System with  
Reference Std. On Nozzle

- **Set-up Specifics**

- Linear Array Probe 10Mhz 64 elements - element size 0.5mm X 5 mm - 64elements
- R/D Tech 128 pulser/receiver Focus System w/Rover Scanner
- Focal law = 16 elements, 48 laws per angle (indexed forward @ each focal law i.e., law 1-16, 2-17, 3-18 etc.)
- Focal laws created to focus the beam @ a depth of 0.2"
- Coupling "localized immersion" bath
- Angle of shoe 19 degrees
- Data points were taken @ 0.020" intervals along the X axis (length of weld)

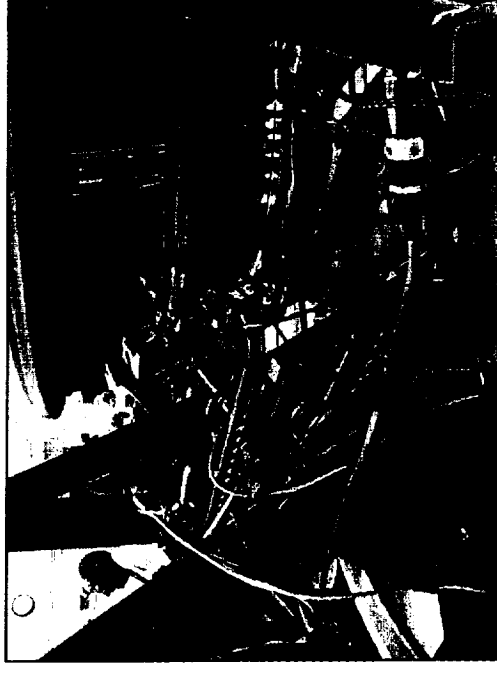




# Phased Array Ultrasonic Examination of SSME Nozzle Weld

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- **Phased Array Ultrasonic Evaluation Results**
  - Revealed two responses less than the .012" deep X .300" long EDM notch.
  - Both responses measured approximately .200" long and less than .012" deep
- **Conventional Ultrasonic Evaluation Results**
  - Could not distinguish the two Phased Array responses above the noise level.
  - Concluded that the indications were smaller than the .012" deep X .300" long notch in reference standard.





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**.024" deep EDM notch @ a 5:1 S/N ratio**







(FWD)

WELD

1.200'

.200'

.850' - .900'

.300' - .400'

# PHASED ARRAY ULTRASONIC RESPONSES

— X-RAY INDICATIONS\*

\* Potential X-ray indications were found to be at the center of the weld

\* Final ultrasonic evaluation revealed the indications are located forward of weld centerline.

